AFRL-VS-HA-TR-2004-1028

SENSOR DEVELOPMENT THERMOSPHERIC NEUTRAL WIND MEASUREMENTS

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15 November 2003

Final Report

20040604 107

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* 15-11-2003	**2. REPORT TYPE** FINAL	**3. DATES COVERED** *(From - To)* 17 May 01 - 30 Sep 03

4. TITLE AND SUBTITLE
Sensor Development Thermospheric Neutral Wind Measurements

5a. CONTRACT NUMBER
F19628-00-C-0028

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
61102F

6. AUTHOR(S)
R. A. Heelis

5d. PROJECT NUMBER
2310

5e. TASK NUMBER
GD

5f. WORK UNIT NUMBER
AM

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Texas at Dallas
Center for Space Sciences
P. O. Box 830668 MS/FO22
Richardson, TX 75083-0688

8. PERFORMING ORGANIZATION REPORT NUMBER
UTD-STR-A002-01-630117

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory
29 Randolph Road
Hanscom AFB MA 01731-3010

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/VSBXR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-VS-HA-TR-2004-1028

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This report summarizes activites related to the development of a sensor to measure the in-situ neutral wind from a satellite in low-earth orbit. This development work sponsored by the Air Force allowed a credible proposal for flight instrumentation to be submitted to NASA. That proposal was subsequently funded and paved the way for a collaborative investigation of ion-neutral coupling of scientific and technical value to both NASA and the Air Force. The project started a conceptual design for neutral wind sensors, the development of computer models of the instrument performance, evaluation of the instrument optics, design and construction of laboratory prototypes, and final construction of flight hardware. We briefly review the activities here making reference to previously released reports that provide more detail.

15. SUBJECT TERMS
Thermosphere
Neutral wind measurements
Radio scintillation

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Bronek Dichter
UNCLAS	UNCLAS	UNCLAS	SAR		**19b. TELEPHONE NUMBER** *(include area code)* 781-377-3991

CONTENTS

FIGURES

1. INTRODUCTION

The challenge we address relates to the specification of the dynamics of the thermosphere and its relationship to severe radio scintillation seen in space and on the ground. This specification must include a description of the neutral air wind velocity. In the upper atmosphere a satellite moves supersonically through the neutral gas and thus the spacecraft motion dominates the neutral gas velocity with respect to the sensor. Then three mutually perpendicular components of the neutral wind velocity can be measured using sensors designed to view the atmosphere approximately along the direction of motion of an orbiting satellite. Two sensors comprise the Neutral Wind Meter (NWM) that will provide a measure of the neutral wind velocity in the sensor reference frame. The ram wind sensor (RWS) will measure the neutral gas velocity along the sensor look direction called the ram wind component. The cross-track sensor (CTS) will measure the angle of arrival of the neutral gas in two mutually perpendicular planes with respect to the sensor look direction. A simple tangential relationship between these two parameters allows the cross-track wind components to be derived as shown in figure 1.

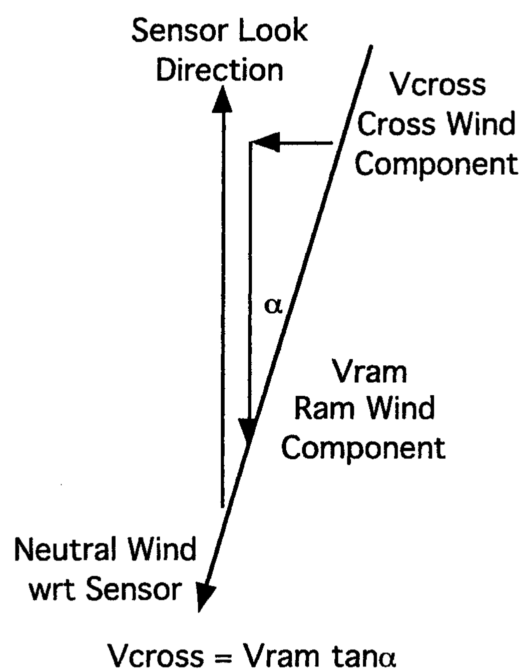


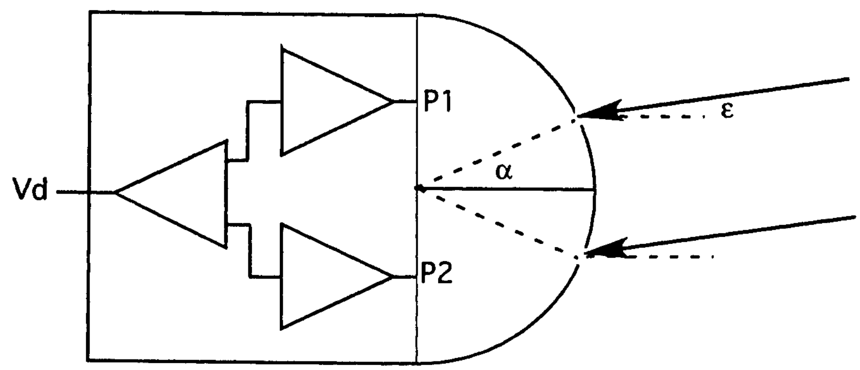
Figure 1. Geometrical Relationship Between Cross-Track and Ram Wind Components

2. INSTRUMENTATION

Two sensors that make up the NWM have been designed, constructed and extensively tested. A flight opportunity for these sensors will appear in November 2004 and at that time we expect to realize the first in-situ measurements of the neutral wind.

2.1 Cross-Track Sensor

The cross-track wind sensor is a differential pressure gauge that measures the neutral gas arrival angle by determining the ratio of the pressures in two adjacent pressure chambers that have small apertures making small angles with the ram direction. Figure 2 is a schematic illustration of the principles of operation making use of the simple relationship between the pressure ratio, obtained by taking the difference between outputs proportional to the logarithm of the pressure, and arrival angle of the gas.



$$V_d = G_d C \ln\left(\frac{P_1}{P_2}\right) = G_d C \ln\left(\frac{\cos(\alpha - \varepsilon)}{\cos(\alpha + \varepsilon)}\right)$$

Figure 2. Schematic Illustration of Arrival-Angle Measurement Scheme.

To simulate and verify the expected performance of this arrangement we must individually establish the behavior of the gauge and its associated logarithmic electrometer and of the difference amplifier used to determine the pressure ratio. It can be shown that the pressure in the chamber varies as the cosine of the angle of attack. Thus near zero angle the change in the pressure with angle is small. The challenge is therefore to provide an angle large enough to provide a meaningful angular variation but not so large that the pressure is too small to provide a good signal. We choose 22.5 degrees as the initial angular offset for this instrumentation. Figure 3 shows the output from an initial evaluation of the instrument performance. It shows that we may expect a pressure enhancement due to the spacecraft motion of about 20 and that even angles as small as 0.1 degrees can be measured if we can measure changes in the pressure of one part in one thousand.

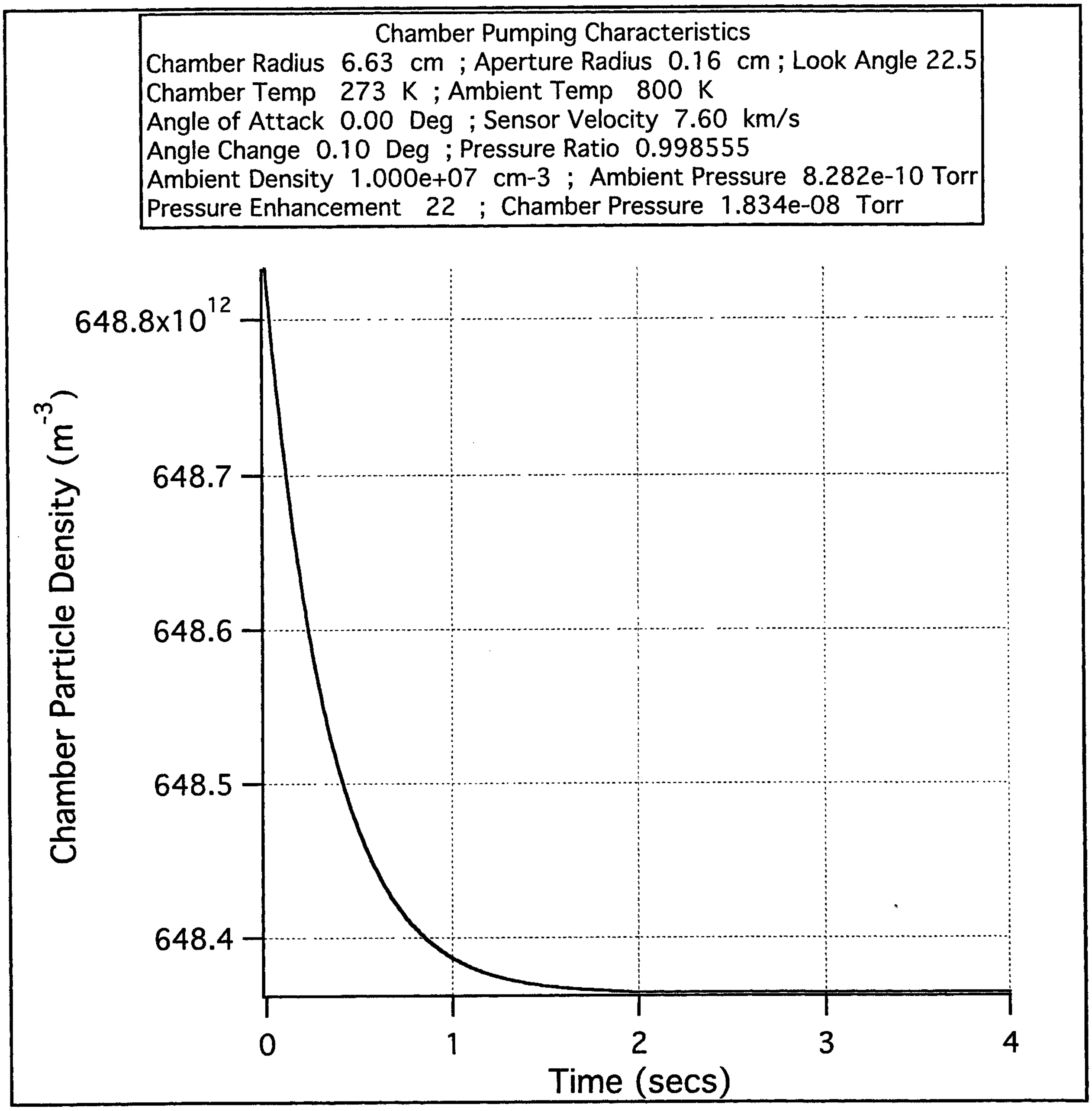


Figure 3. Computed Cross-Track Wind Sensor Performance.

Based on these expectations we designed and built the necessary hardware and electronics. Extensive testing of the instrument performance subsequently verified the expected performance and showed that we could build ionization gauges and associated electronics with the required sensitivity.

2.2 Ram Wind Sensor

The ram wind sensor derives the velocity along the ram direction by performing a retarding potential energy analysis on an ionized fraction of the flowing neutral gas. The incident ambient ions are electrostatically deflected from the instrument axis so that only the ions produced from the flowing neutral beam have access to the electron multiplier detector. A schematic illustration of the sensor configuration is shown in figure 4.

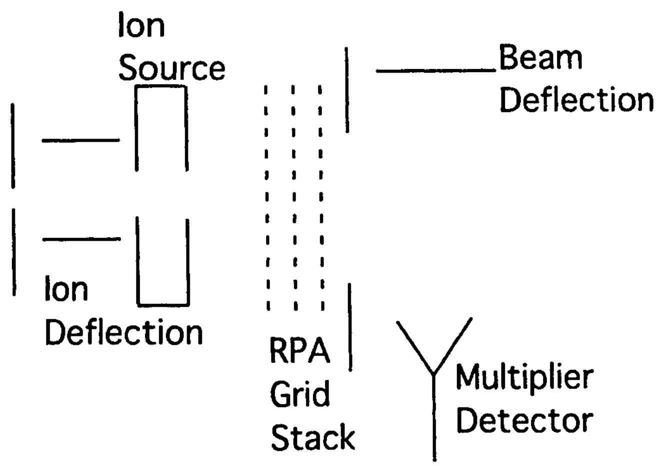


Figure 4. Schematic Illustration of Ram Wind Sensor Configuration.

Extensive laboratory testing of this configuration was made possible with support from this contract. In the laboratory it was necessary to add a bias grid to eject ions from the ion source since the spacecraft motion is not easily reproduced in a neutral beam. With this limitation we were able to show that the ion optics functions in an acceptable way and that the ion beam is completely collected even after substantial deviations produced when the retarding potential approaches the beam energy.

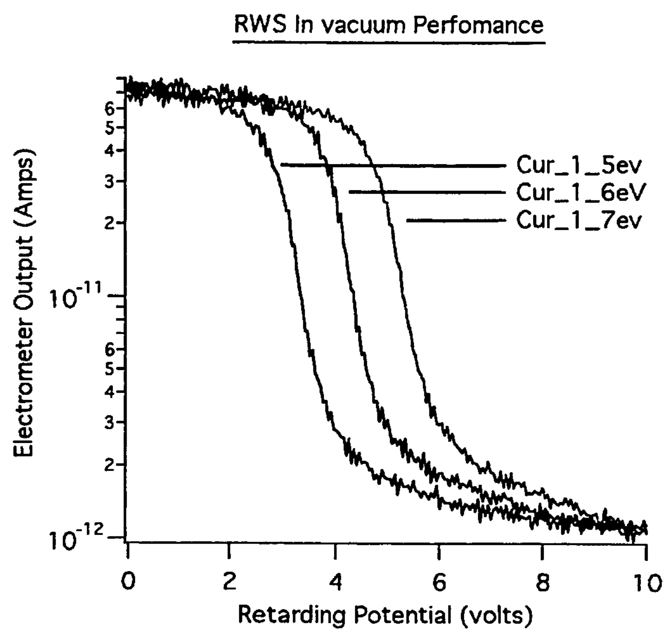


Figure 5. Ram Wind Sensor RPA Characteristics.

Figure 5 illustrates the laboratory outputs obtained when the draw-out potential was moved successively by one volt. This data provided the momentum to proceed toward the design of hardware and control electronics suitable for flight operations.

3. CONCLUSIONS

This research effort has resulted in the design and verification of a robust space instrument to measure the F-region neutral wind vector. The performance evaluation and verification work described here has been part of the overall effort to provide flight hardware and software for satellite borne instrumentation. The production of flight hardware and associated software development has been transitioned to a NASA supported effort but will also contribute substantially to the Air Force operational goals for forecasting radio scintillation. We now confidently look forward to obtaining essential measurements of the equatorial F-region neutral wind during the C/NOFS program.